# Steps Towards an Earth System Data Assimilation Capability in the GMAO

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On behalf of the GMAO

# Overview of Presentation

Scope of the GMAO's activities

Seasonal Forecasting

MERRA-2 Reanalysis – a step towards an Earth System Reanalysis

Weather and Air Pollution

Summary

# Themes of GMAO's work

- Weather Analysis and Prediction
- Seasonal-to-Decadal Analysis and Prediction
- Reanalysis
- Global Mesoscale Modeling
- Observing System Science

- These (non-orthogonal) themes span GMAO's main focus areas
- Strong emphasis on NASA's Earth Observations (use, support, planning)
- GEOS is a modular system: configuration changes resolution, complexity of process, etc.

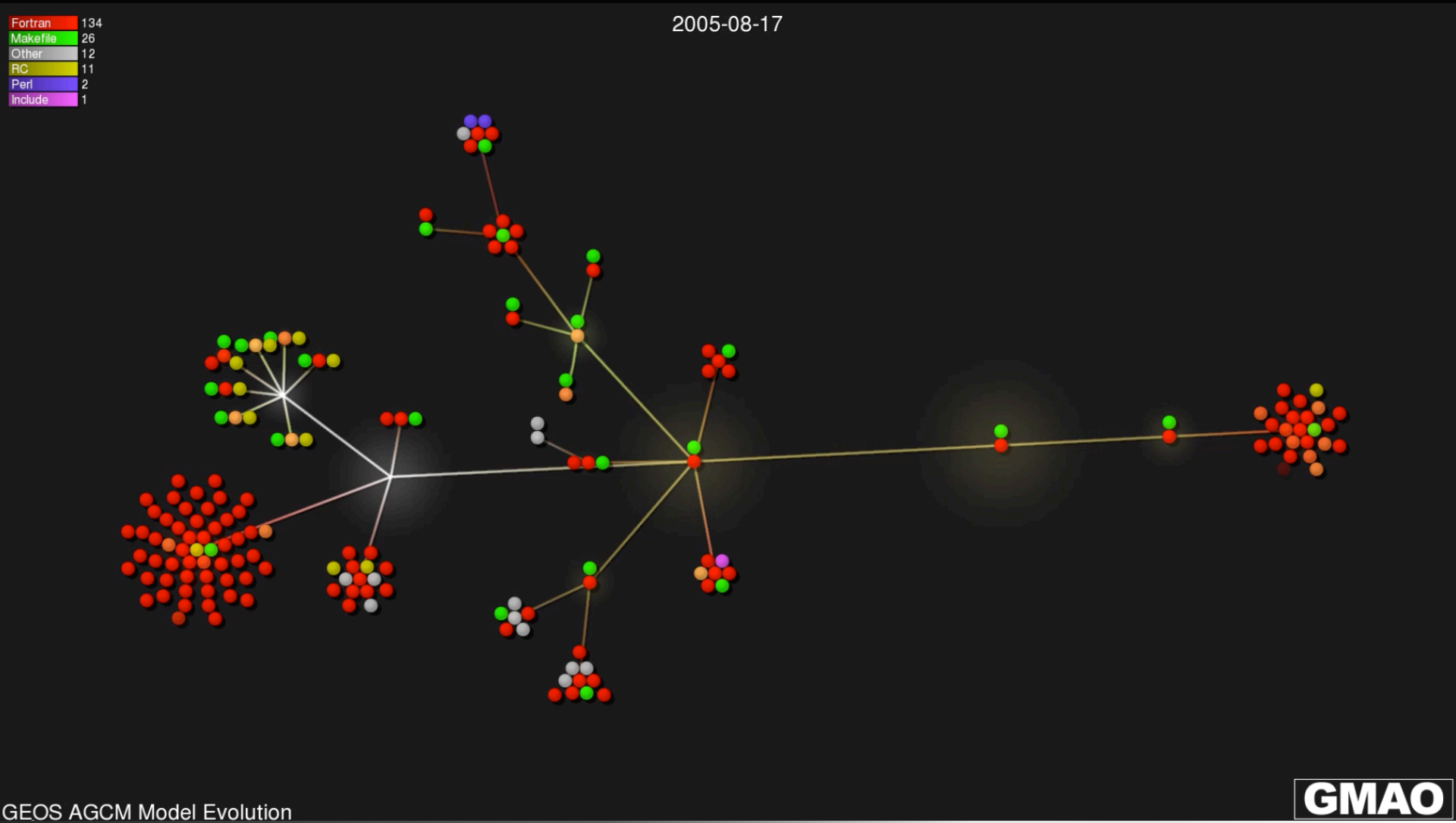
## Increasing complexity of the GEOS atmospheric model

The following animation illustrates the growth of the GEOS model over the past decade (or so)

The ESMF structure adopted for GEOS facilitates the modular structure

Various alternatives are available for several of the processes represented in the model

Animation: Matt Thompson




GEOS AGCM Model Evolution

GMAO

# Some Features of the GEOS “FP” (Weather) System

GMAO’s “flagship” analysis/forecasting system

Assimilates multiple datasets, as in operational weather centers

In January 2017, GEOS-FP transitioned to a “hybrid 4D Ensemble-Variational” assimilation system with resolution around 12km

GMAO has pioneered the use of new data types in this system – soon to include the all-sky GPM radiances

Monitoring of observation impacts is a critical part of our mission

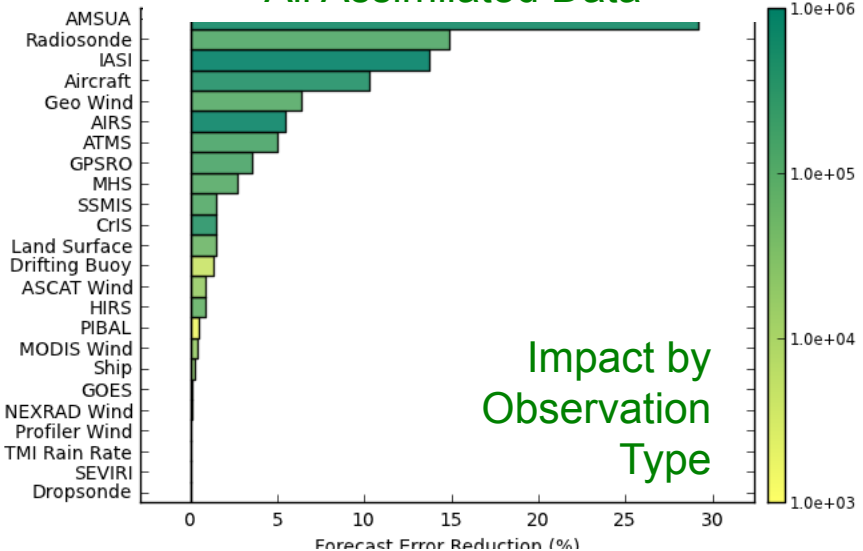
Simultaneous focus on ozone (NASA data), aerosols (NASA data, A da Silva presentation)

Wide use in numerous groups, including NASA field missions: air pollution, high-latitude systems, …

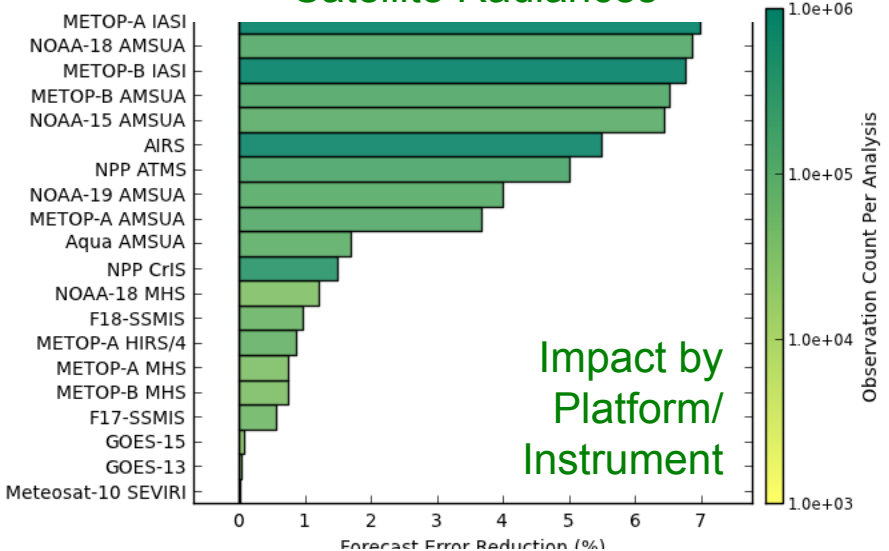
# Observing System Impacts in Numerical Weather Prediction

GMAO has developed adjoint-based sensitivity diagnostics that isolate the impact of all observation types. These are now released as part of GMAO's product suite.

## All Assimilated Data




## Satellite Radiances




Results for July-August 2014, including the GPSRO, Suomi-NPP (ATMS and CrIS), and MetOp-A and B (IASI, AMSU-A, MHS) radiances. The fractional impact on 24-hour forecast error reduction is shown.

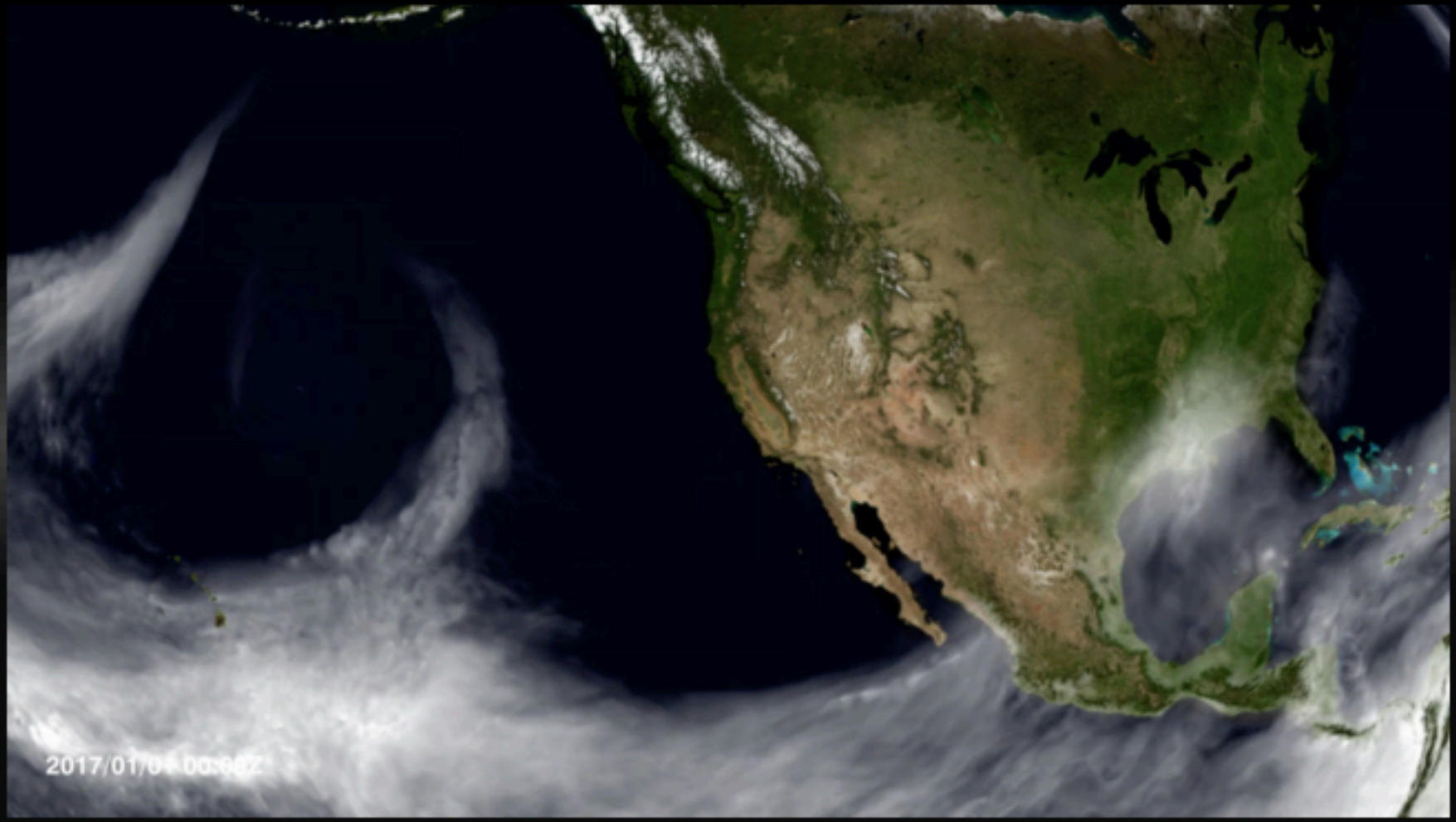
## Atmospheric Rivers and California Rain

Drought-breaking precipitation over the West coast came in the form of atmospheric rivers in early 2017

This animation illustrates these events using cloud fields from GEOS along with precipitation from GPM

Good general agreement between the GEOS clouds and the GPM precipitation

Animation: NASA's SVS with Duane Waliser (JPL)


2017/01/01 00:00Z

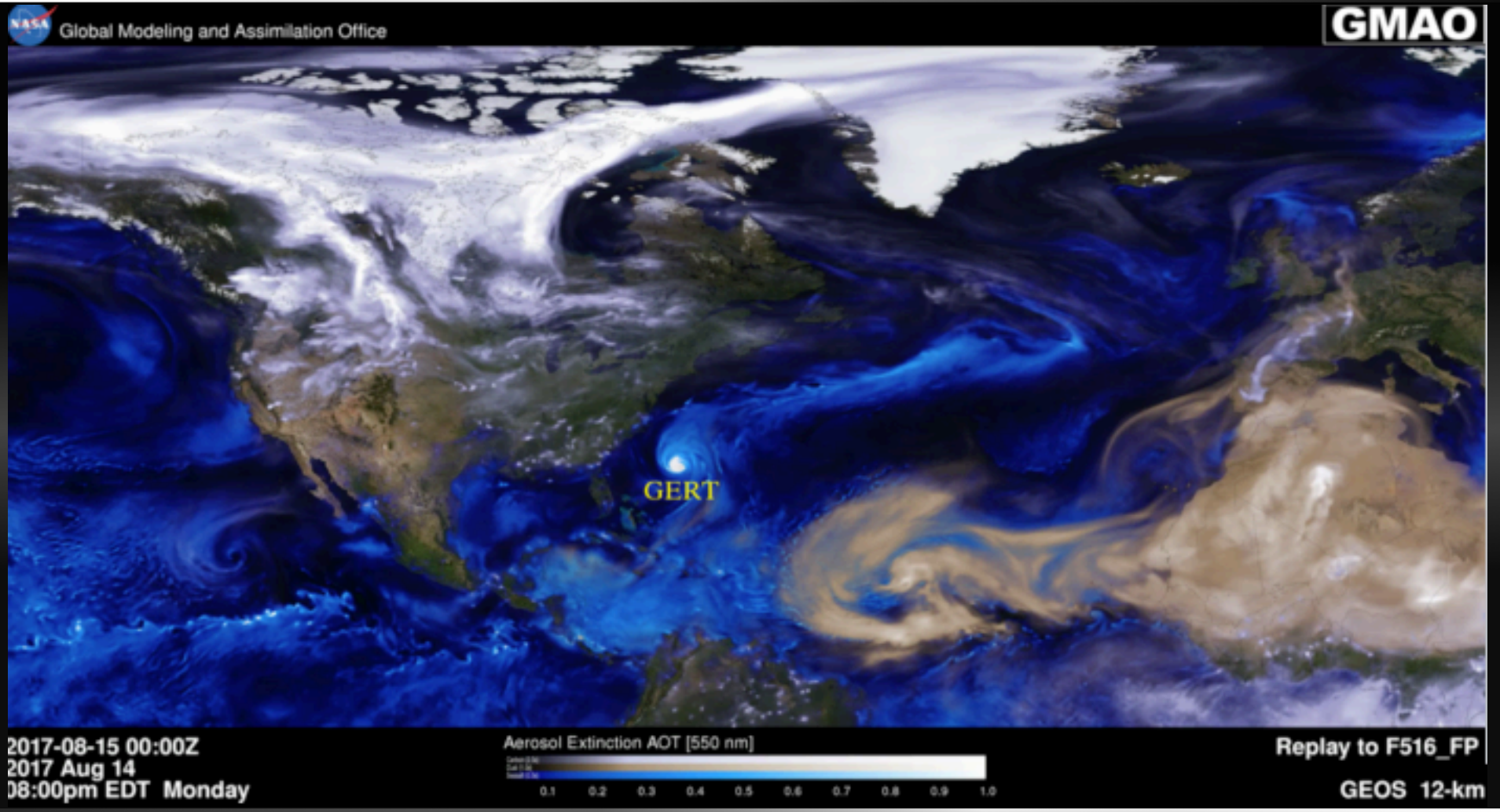
## GEOS “weather” analyses

The American summer of 2017 was characterized by extreme events: hurricanes and severe wild fires

The GEOS analyses capture the simultaneous occurrence of these events

This work depends heavily on the use of NASA data: AIRS and MODIS play a prominent role

Animation: Bill Putman


Global Modeling and Assimilation Office
GMAO
GERT
2017-08-15 00:00Z
2017 Aug 14
08:00pm EDT Monday
Aerosol Extinction AOT [550 nm]
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Replay to F516_FP
GEOS 12-km

# Some Features of MERRA-2

GMAO's latest reanalysis: replaced MERRA (turned off on Feb 29, 2016)

Half-degree assimilation system (3D-Variational approach) using GEOS

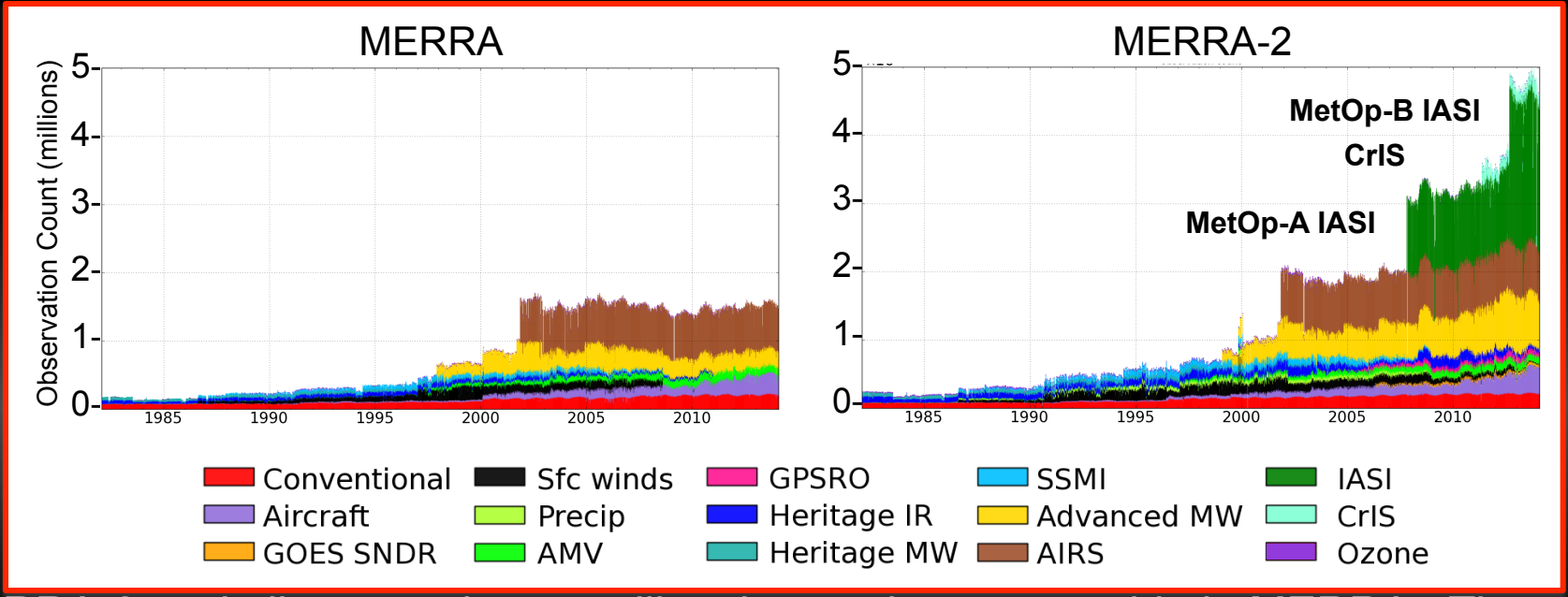
MERRA-2 data are by now widely used, distributed by GES-DISC:

Well documented, including a special section of J. Clim. (M. Bosilovich)

MERRA-2 includes substantial advances over MERRA:

- Increasing focus on the "non-meteorological" aspects:
  - Interactive aerosols
  - Enhanced representation of cryospheric processes
  - Use of NASA data to improve the stratosphere
- Pathway to more complete Earth System Reanalysis

# MERRA-2: Observing System Time Series

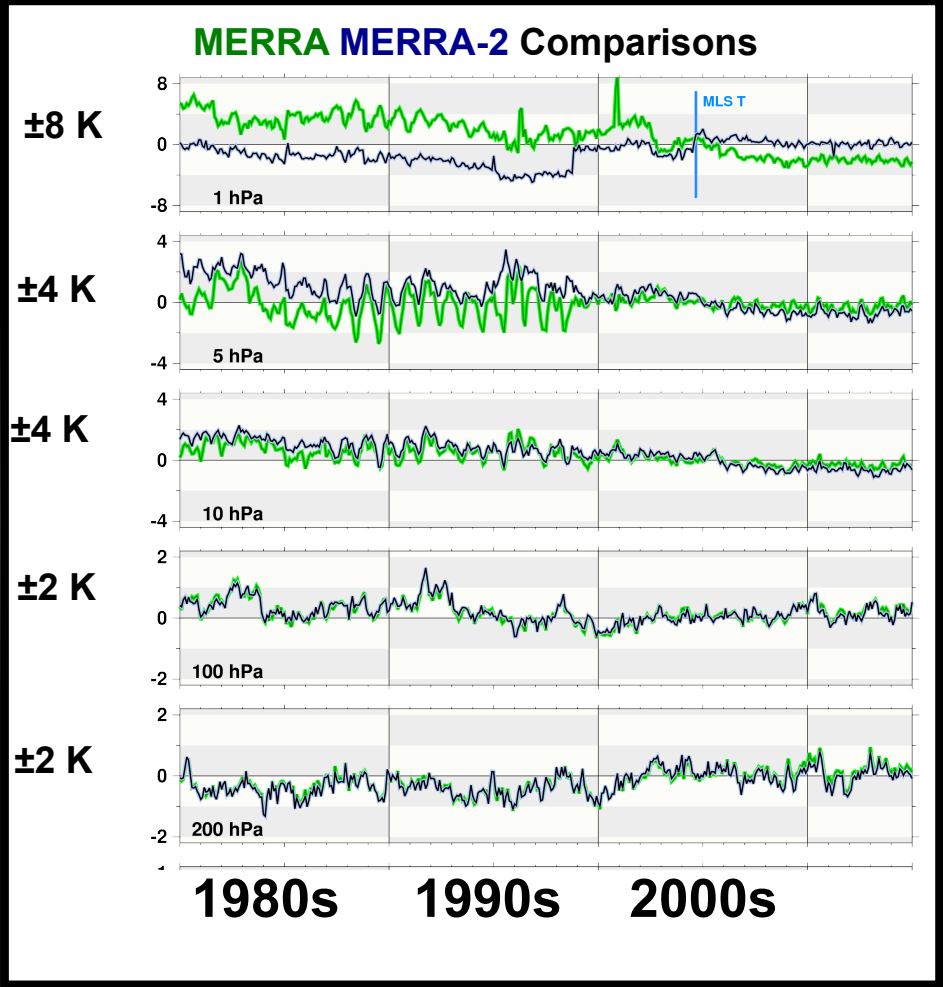



MERRA-2 assimilates modern satellite observations not usable in MERRA. The number of observations in each 6-hr assimilation cycle now approaches five million, as additional hyperspectral sensors such as IASI and CrIS have become active. In contrast, MERRA includes no satellite radiance data types that began operations after 2005. Its data count would drop dramatically if Aqua were to fail.

# MERRA-2: Focus on the Stratosphere

Demonstrating the impact of using NASA's EOS-Aura Microwave Limb Sounder Observations of temperature and ozone in a reanalysis (after 2004)

Also suggests a new emphasis on more complex reanalyses of the 21st Century (EOS period and beyond) – focus on Earth System processes, rather than on "climate diagnostics"



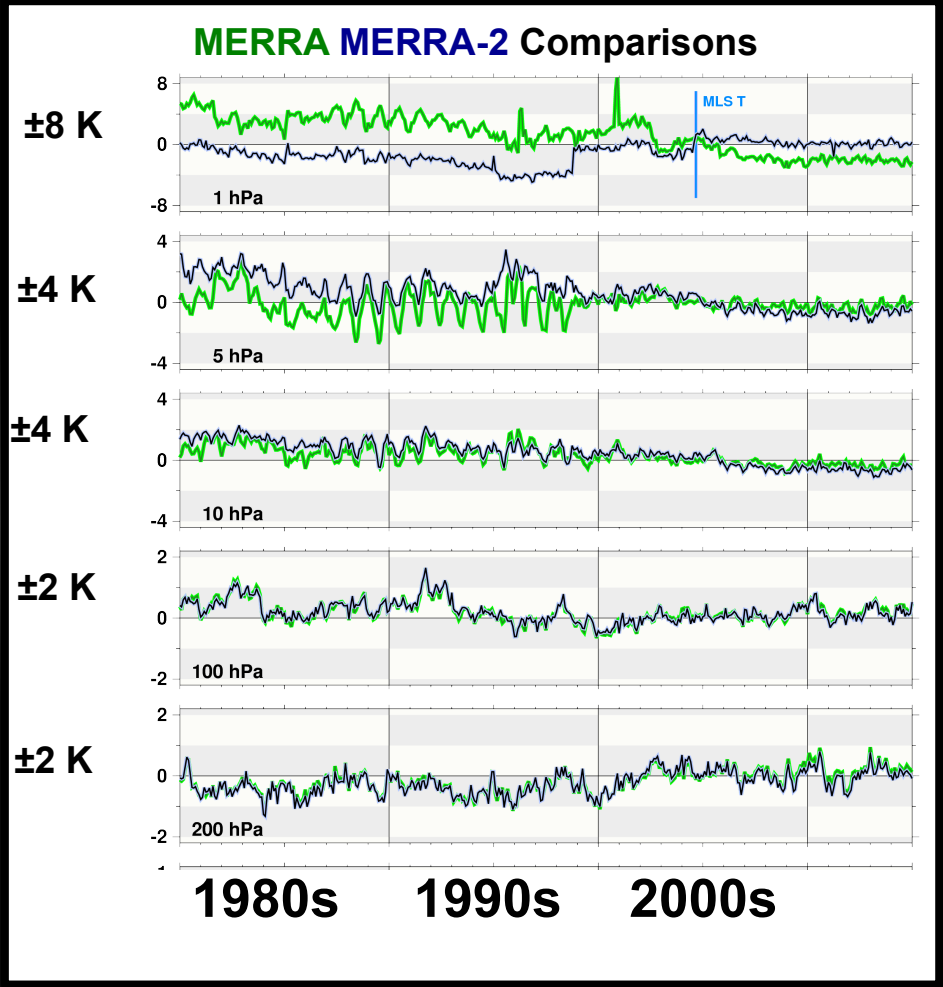

# Global-mean Temperatures

**1 hPa:** Overall, the temperature is more constant in MERRA-2. Jump up in late 90s is similar to ERA-Interim.

**5 hPa**: Large annual cycle in 1990s is reduced in amplitude in MERRA-2.

**10 hPa**: MERRA-2 is slightly warmer in the 1980s. Generally good agreement.

**100-200 hPa:** Overall, the temperature is more constant in MERRA-2. Jump up in late 90s is similar to ERA-Interim (not shown).




# Global-mean Temperatures

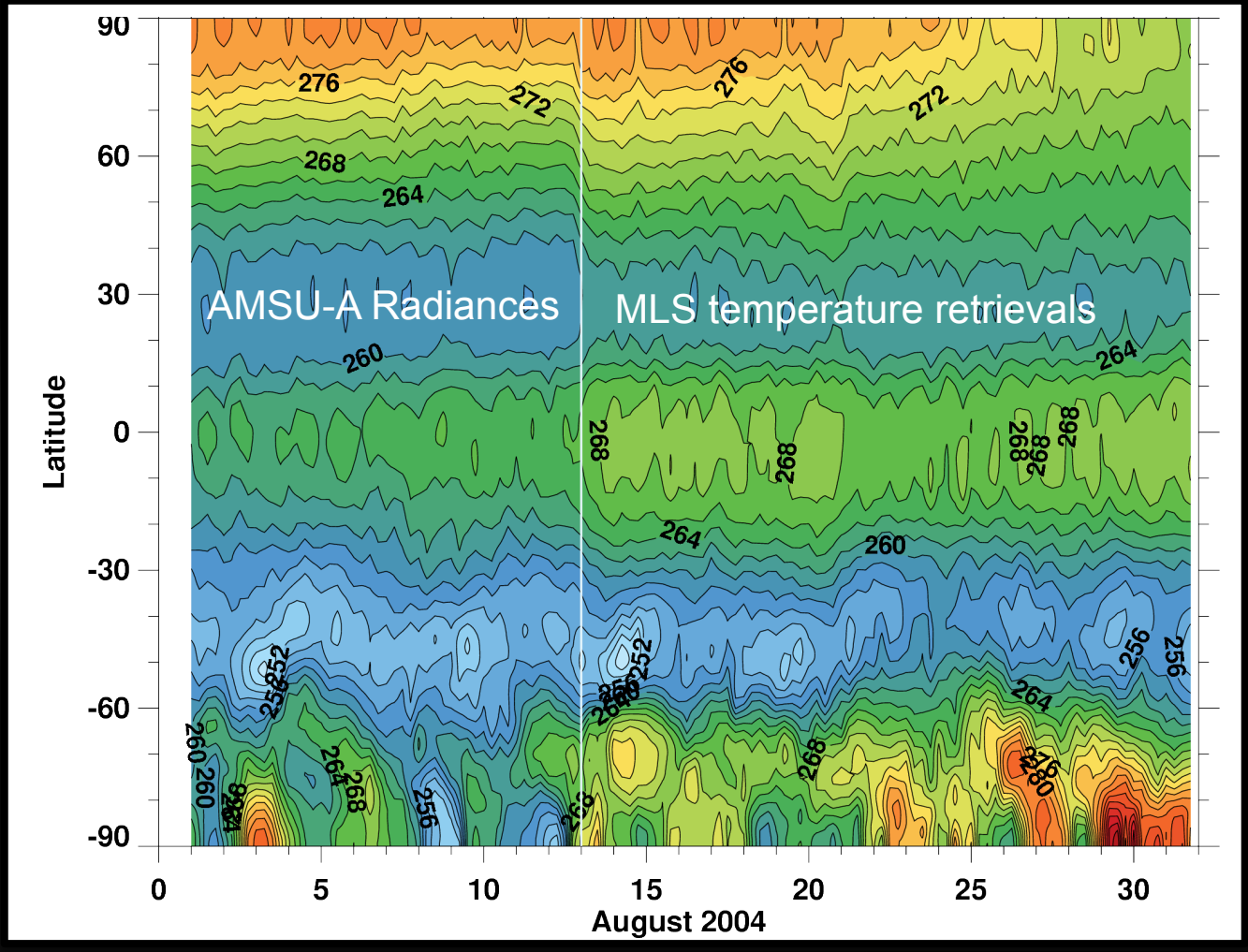
**1 hPa:** Above the peak in SSU and AMSU-A; big differences pre-1997 AND large impact of MLS temperatures post 2004

**5 hPa**: New treatment of SSU radiances (in CRTM) is very evident. TRENDS differ through 2000s.

Many of the stratospheric differences in the 1980s and 1990s are likely due to the use of the CRTM in MERRA-2

MLS temperature have a small impact at 5hPa – larger at lower pressures

# 1-hPa Temperatures

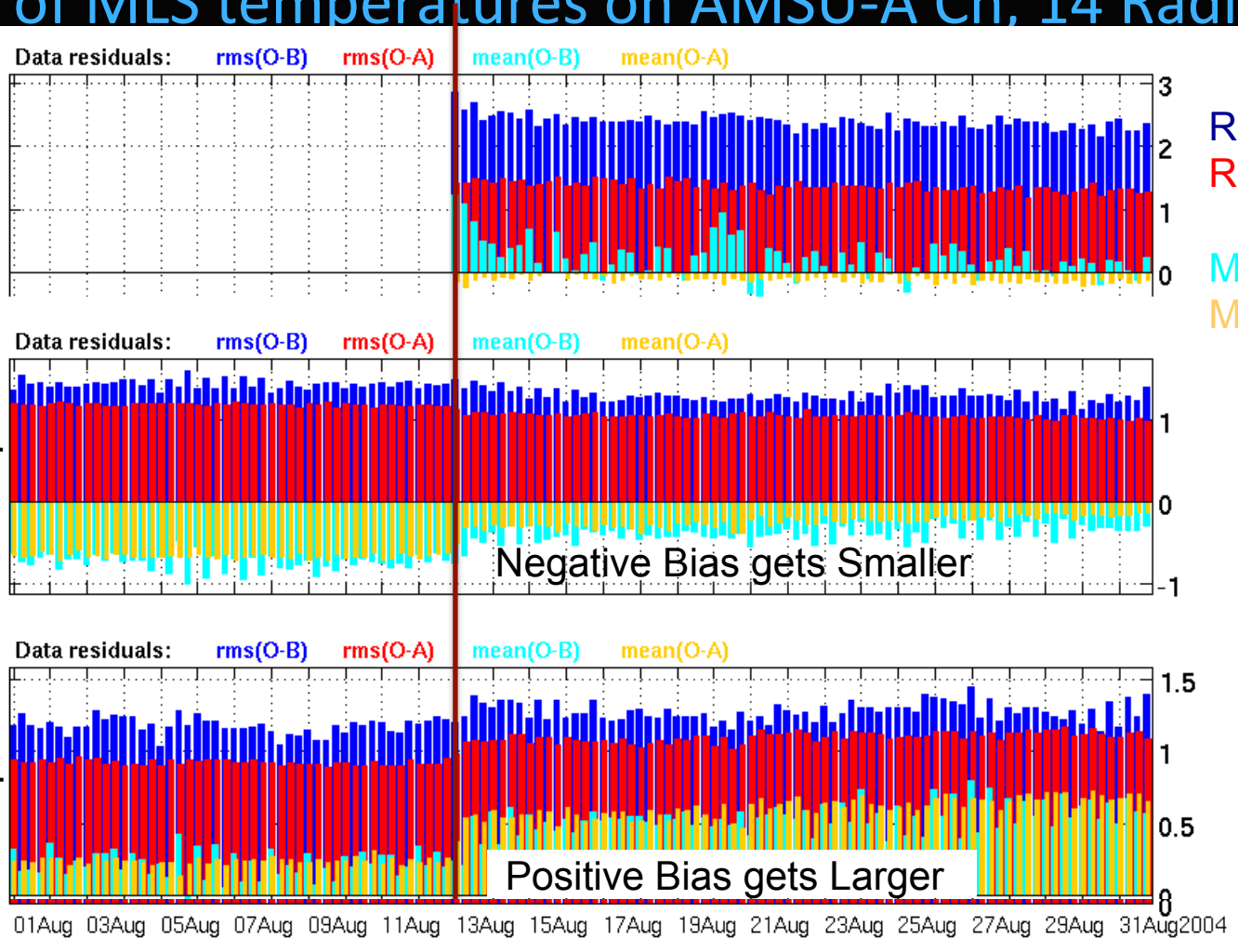


# Impacts of MLS temperatures on AMSU-A Ch. 14 Radiances

MLS Temperature At 1hPa

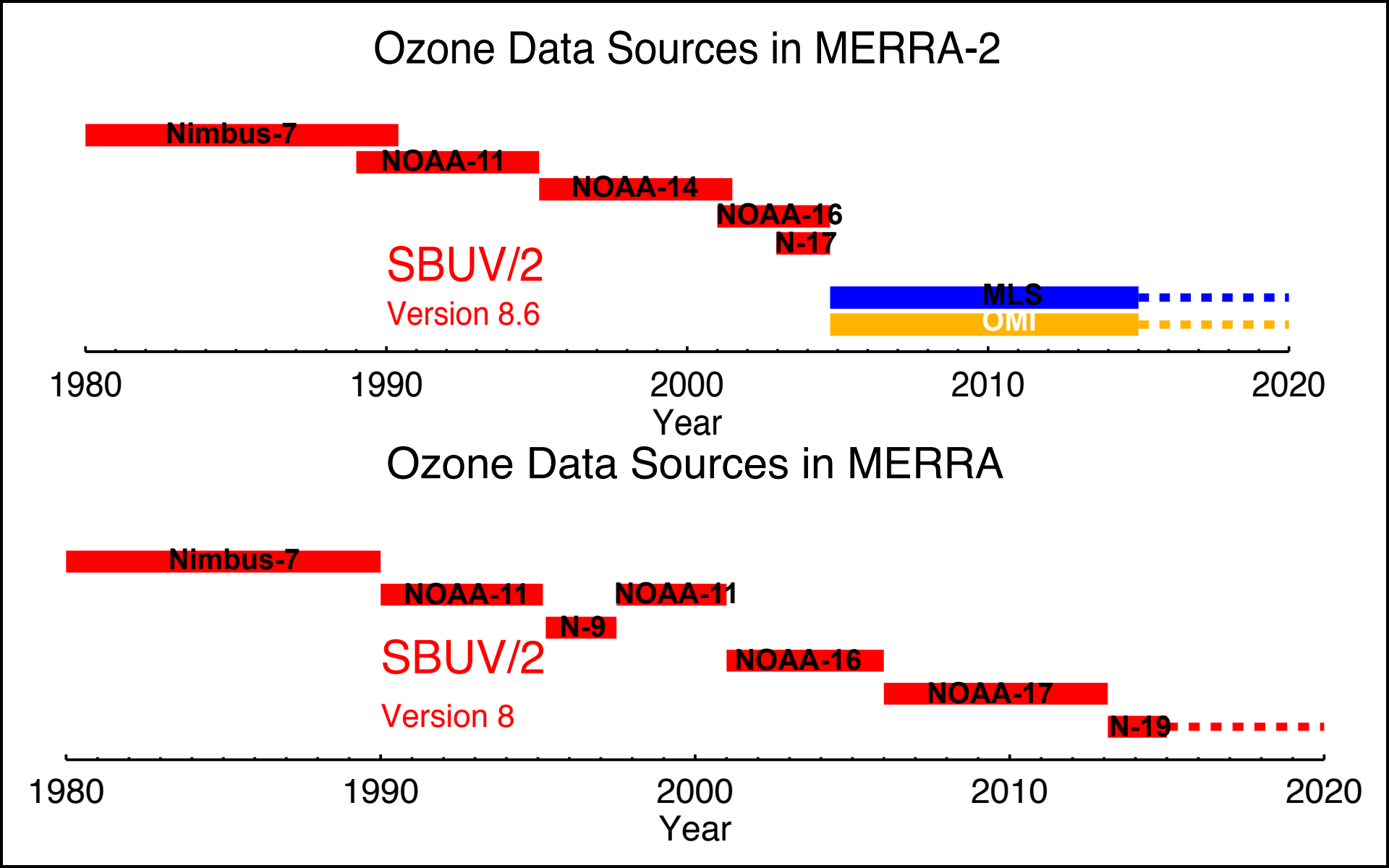
EOS-Aqua AMSU-A Ch. 14 Brightness Temperature

NOAA-16 AMSU-A Ch. 14 Brightness Temperature

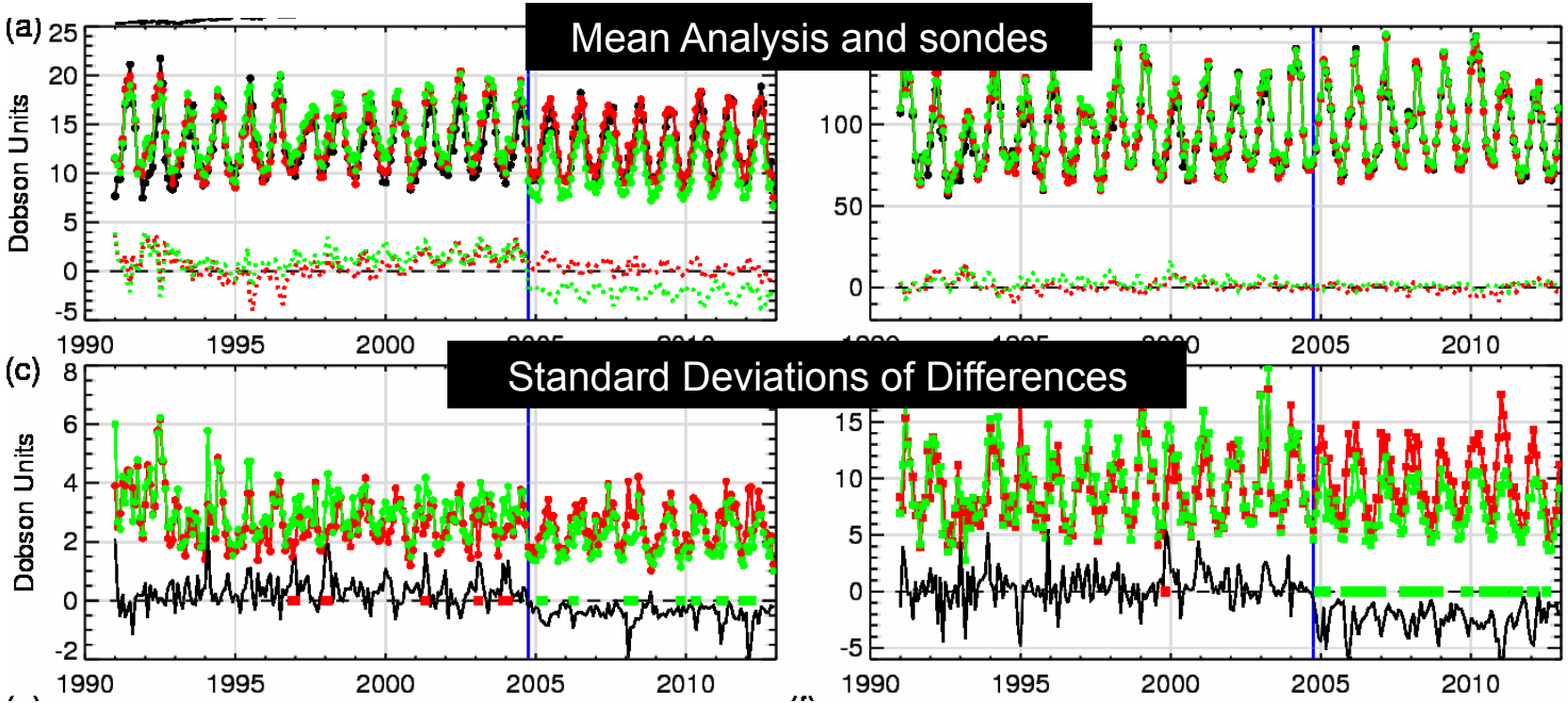



RMS (O-B)
RMS (O-A)

Mean (O-B)
Mean (O-A)


Ozone Data Sources in MERRA-2
Nimbus-7
NOAA-11
NOAA-14
NOAA-16
N-17
SBUV/2
Version 8.6
MLS
OMI
1980
1990
2000
2010
2020
Year
Ozone Data Sources in MERRA
Nimbus-7
NOAA-11
NOAA-11
N-9
SBUV/2
Version 8
NOAA-16
NOAA-17
N-19
1980
1990
2000
2010
2020
Year

# Comparison of MERRA-2 Ozone with Sondes



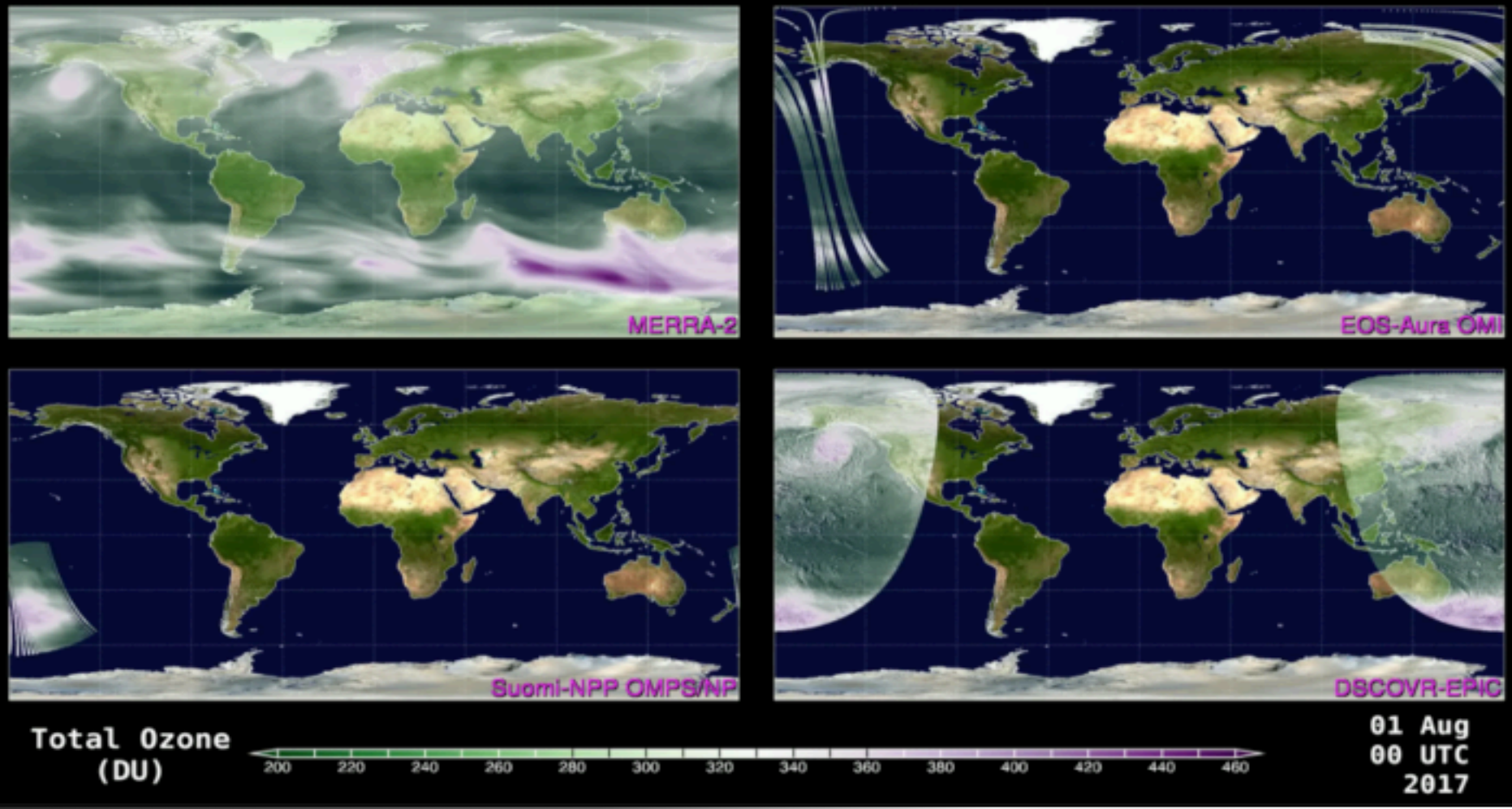
## Ozone in MERRA-2, highlighting the value of assimilation

MERRA-2 ozone is constrained by assimilating SBUV data before 2005 and EOS-Aura OMI and MLS data

Animation of total ozone fields in August 2017 illustrates the sampling of OMI, OMPS-NP, and DSCOVR-EPIC

The dynamic nature of the assimilated total ozone fields is a prominent feature

Animation: Larry Coy


MERRA-2
EOS-Aura OMI
Suomi-NPP OMPS/NP
DSCOVR-EPIC
Total Ozone
(DU)
200 220 240 260 280 300 320 340 360 380 400 420 440 460
01 Aug
00 UTC
2017

# Ocean Analyses (and Seasonal Forecasts)

As part of the seasonal forecasting system, GMAO produces analyses and forecasts of the ocean

A “MERRA-Ocean” dataset has been run for 1979 through 2016, ingesting SST data, altimetry (since 1993 – Poseidon/Jasons), and in-situ profiles and buoy datasets

Substantial work is aiming at a “MERRA-2 Ocean” analysis, targeted for early 2019 release

Target is a 25-km analysis using MOM-5 and bringing in a capability for using NASA’s sea-surface salinity as well other datasets, including the ocean skin-temperature assimilation

**Oct 2017** — Release Version 2 of GEOS-S2S system

- Based on MERRA-2/GEOS FP-IT (c180L72) and “old system”
- MOM-5/CICE (0.5º L40) - not a full ocean/ice assimilation

**Jan 2019** — Release Version 3 of GEOS-S2S system (science system)

- Based on MERRA-2/GEOS FP-IT (c180L72)
- MOM-5/CICE (0.25º L50) – “MERRA-2 Ocean”
- Include Catchment-CN land model and associated DA
- Science tests: data - altimetry, salinity, soil moisture, NDVI; aerosol, ozone, …; methods: ensemble, perturbations, …

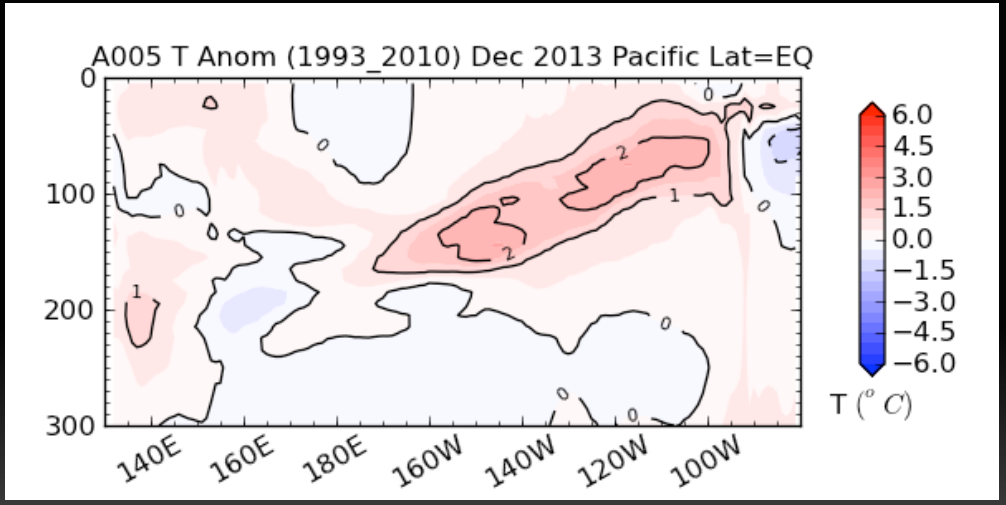
**Jan 2021** — Coupled reanalysis, V4 of GEOS-S2S (target)

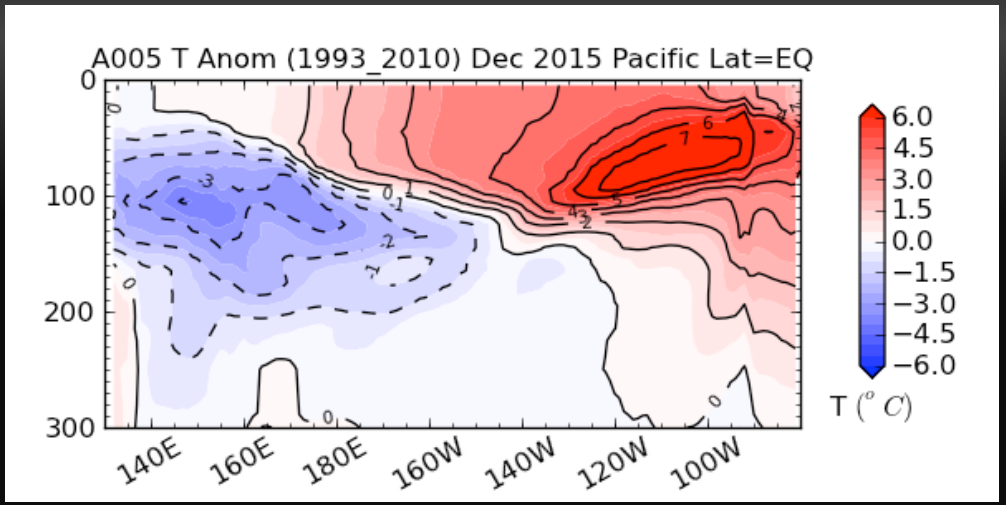
- Coupled system, circa c360 (25km) resolution
- Coupled-at-the-interface DA

# Pacific Ocean Temperature Anomalies

Comparison of temperature anomalies at the Equator in the Pacific Ocean in December 2013 and 2015.

The strong El Niño clearly dominates the sub-surface ocean in December 2015, with cold regions at the Western boundary (Indonesia) and warmer waters from the central Pacific to the South American coast.



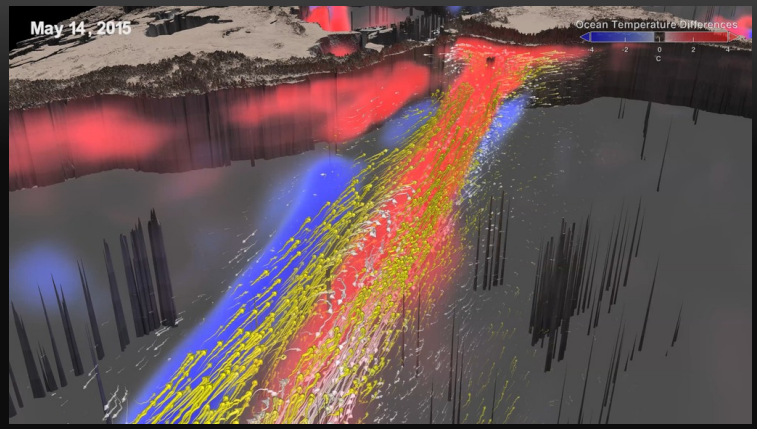



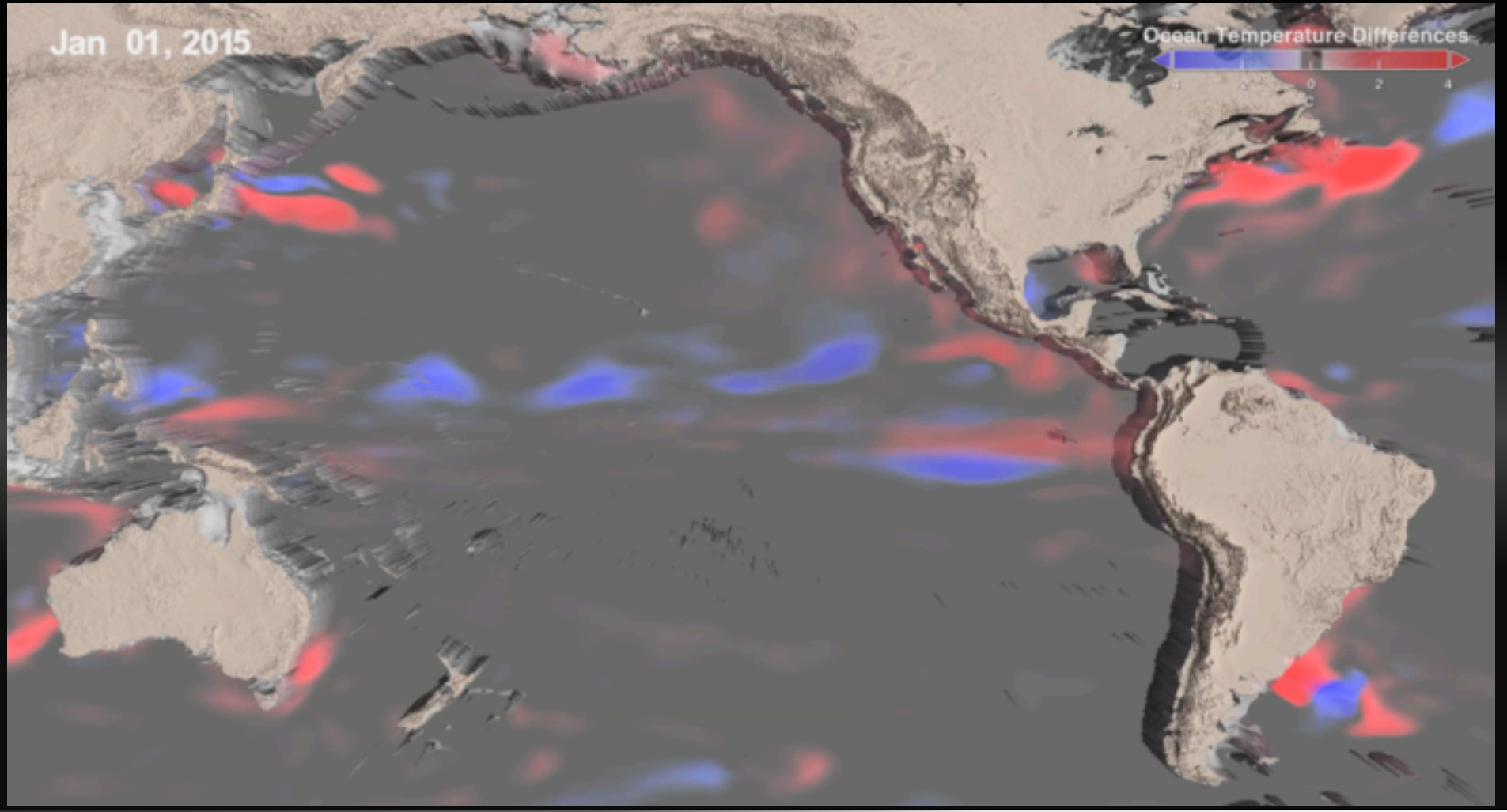
## An animation of the 2015-2016 El Niño Event

Illustrating the anomalies in 3D near-surface oceanic temperature across the Pacific basin

Ocean currents are included in the assimilated product, a consequence of the use of the model

Animation: NASA SVS




Jan 01, 2015
Ocean Temperature Differences
-4
-2
0
2
4

# Three-Dimensional Chemistry

Through a long-standing collaboration with the Harvard University Atmospheric Chemistry Modeling Group (Jacob-Pawson) NASA have funded development of the GEOS-Chem chemistry model for use in GEOS systems

As a research project, we began running a full chemical forecasting system in early 2017

This is a c360 (25km) global system, currently without assimilation of constituents, for which one five-day forecast is run each day

Assimilation of chemical species will gradually be worked in. The assimilation will be a separate optimization from the meteorological state.

Preliminary results are very encouraging ...

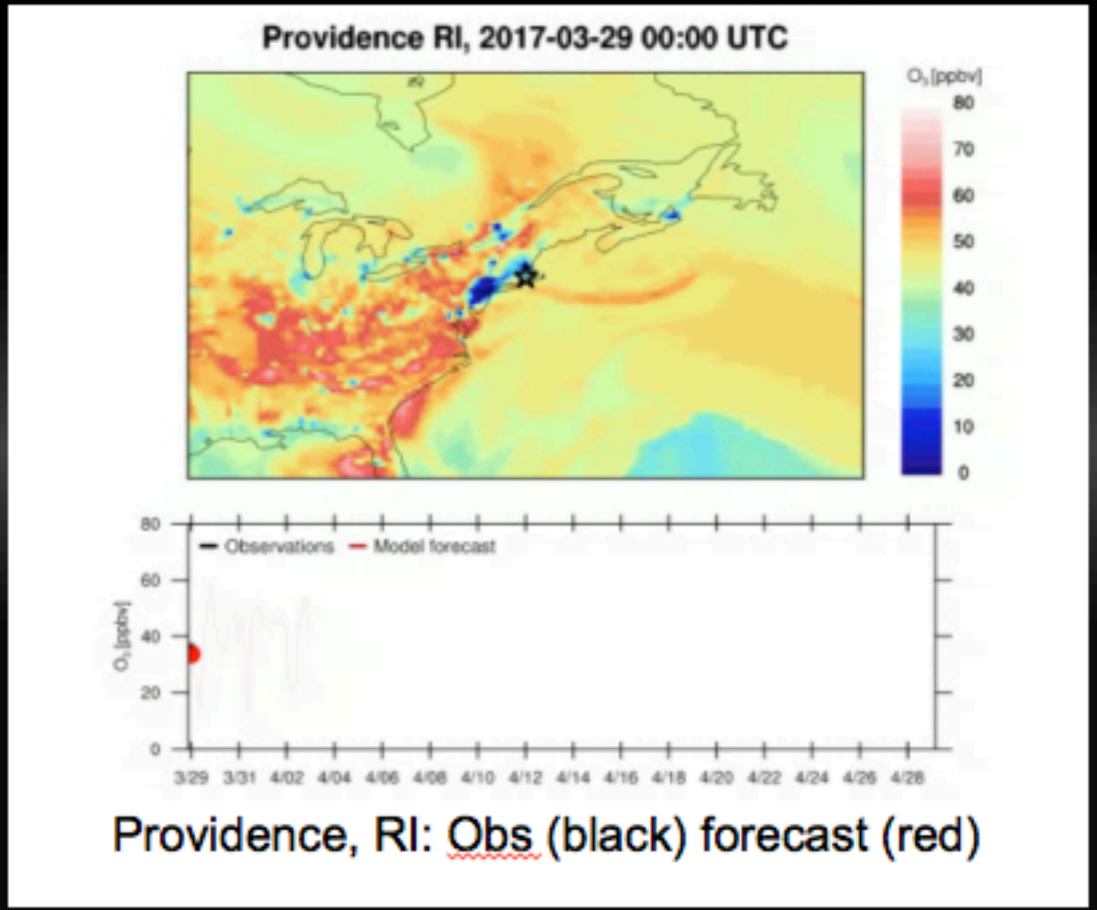
# Surface Ozone from GEOS model with GEOS-Chem

c360L72 configuration of GEOS system (~25km or 0.25 degree)

Meteorology "replayed" to GEOS-FP (c720L72)

One five-day forecast produced each day

Completed by about 9AM EST



## Global Health Air Quality Index

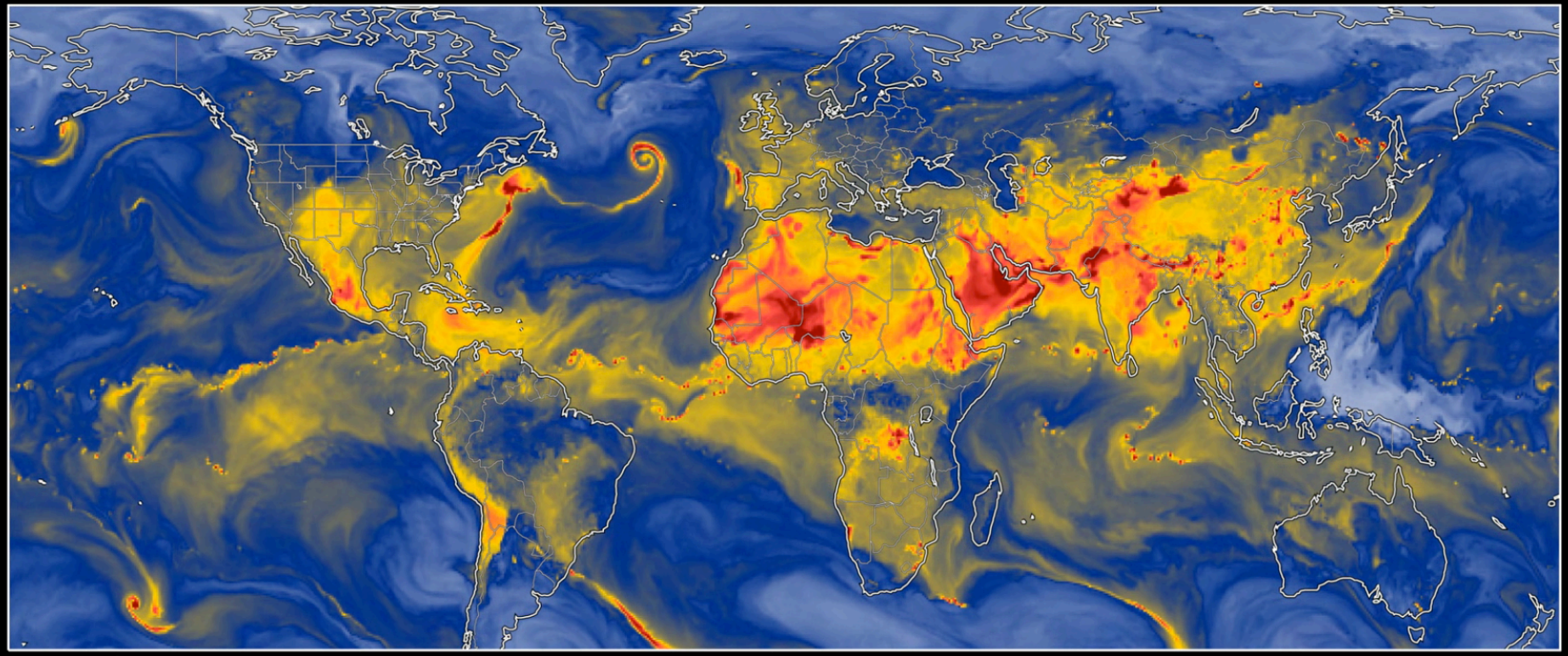
Combines the new ozone and $NO_2$ information from GEOS with GEOS-Chem chemistry and aerosol information

Aerosols are the focus of Arlindo's presentation (coming up next!)

Highlights the dynamic nature of surface air pollution and the possibilities being opened by this work

Animation: Christoph Keller/Emma Knowland/Eric Nielsen

# Health Air Quality Index



GEOS-5 1/4°

GEOS-Chem v11-02

Tue 23 May 2017 | Wed 24 May | Thu 25 May | Fri 26 May | Sat 27 May

0 1 2 3 4 5 6 7 8 9 10

GMAO

Global Modeling and Assimilation Office
NASA Goddard Space Flight Center

Atmospheric Chemistry Modeling Group
Harvard University

# Summary

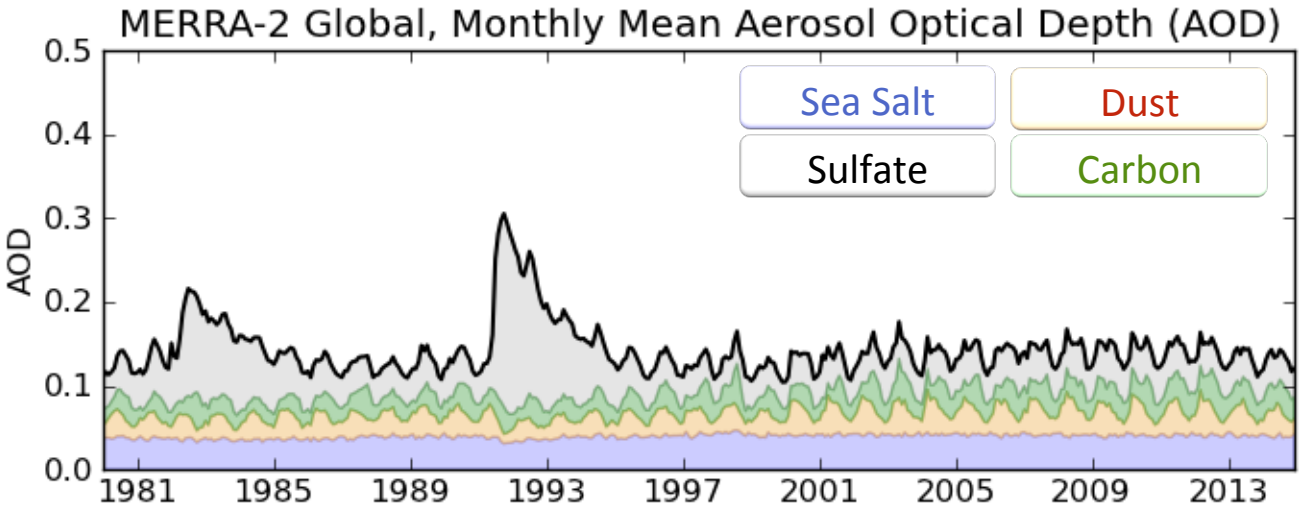
GMAO is active in extending GEOS systems to encompass many aspects of the Earth System

Have focused on a few examples that illustrate our current capabilities and are steps on the pathway to future growth

GMAO's work links strongly to NASA's Earth Observations:

- Use of GEOS products by instruments teams (such as CERES)
- Ingest of NASA data to demonstrate their value in Earth System Analyses
- Planning for new NASA missions

# MERRA-2: Atmospheric Aerosols




MERRA-2 uses satellite data (MODIS and AVHRR) to constrain aerosol optical depths, as well as to compute aerosol emissions due to biomass burning

# Overview

Objectives today:

- Summarize timelines from a “products” perspective (broad brush)
- Start to align products with “developments”
- Start to put names to tasks/responsibilities

## Increasing complexity of the GEOS atmospheric model

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